E7.4- 1 0.3 0.4

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Mapping Suspended Particle and Solute Concentrations from Satellite Data

A. N. Williamson
Research Physicist
U.S. Army Engineer Waterways Experiment Station
P. 0. Box 631
Vicksburg, Mississippi   39180

INTRODUCTION

A long-range goal of the Corps of Engineers is to develop the capability of predicting the dispersal of water constituents (i.e. sediments, nutrients, pollutants, salinity, etc.) in estuaries. If such predictive capabilities were available, they might eventually lead to methods of predicting and managing the biological populations in the estuary and related waters.

Attempts to develop estuarine dynamics models have clearly demonstrated that it will be necessary to monitor the movements of the various water masses (i.e. the discharges of the various rivers as well as in-flowing marine waters) through the system in order to validate the models. Ideally, this implies a set of synoptic records of conditions within the estuary and related waters over some period of time. While this kind of record is effectively impossible to obtain with conventional methods, the ERTS-1 offered the possibility of a practical method, provided the ERTS multispectral scanner could be used to (a) map the planimetric distributions of suspended sediment concentrations in estuarine waters, and (b) differentiate different sediment types by exploiting their differences in spectral reflectance.

Concept

The ERTS-1 MSS is comparable in some respects to a reflectance spectrophotometer that is commonly found in materials testing laboratories. A reflectance spectrophotometer (fig. 1) contains a source of radiation, a prism or grating for separating light reflected from a material under test into its spectral components (spectral radiance), a detector that converts spectral radiance into an electrical analog, and a device for recording the output of the detector. The ERTS-1 has the sun as its source of radiation. Radiant energy reflected from the earth's surface (spectral reflectance) is detected by a multispectral scanner (MSS) on board the ERTS-1 (fig. 2). The MSS separates the energy it receives into four spectral bands: 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 micrometers. Energy detected in each band is converted to an electrical analog which, in turn, is converted to digital form and transmitted via telemetry to ground receiving stations. At the ground receiving stations, the data are recorded on computer compatible magnetic tapes (CCT's).

Encl 1

In order to better understand the information content of the CCT's, consider
the measurement sequence of the MSS. The instantaneous field of view of the
MSS (fig. 3) encompasses an area on the terrain surface (picture element or
pixel) of about 1.1 acres. A scanning mirror causes the instantaneous field
of view to be deflected along lines normal to the orbital path of the satellite
and measurements are made at successive intervals along each scan line. In
this manner the MSS sequentially measures the spectral reflectance of 3240
contiguous pixels along each scan line. A total of 2340 scan lines are re-
quired to define an ERTS-1 scene covering an area on the ground 100- by
100-nautical miles. The CCT's contain data for each of the four spectral
bands of the MSS arranged so that the spatial relationship of the measurements
is retained.

Users of MSS data have a choice of exploiting either the CCT's for a scene
or a set of photographs (fig. 4) derived by exposing a piece of photographic
film to a lamp that is intensity modulated in proportion to the radiance level
recorded on the CCT. ERTS data users at the U. S. Army Engineer Waterways
Experiment Station (WES) chose the CCT's because the objectivity required
by the problems we sought to solve with ERTS-1 data dictated that the inter-
pretive process be based on mathematic manipulation of the digital data by
application of computer techniques.

Data Reduction Procedures

In the interest of optimizing data processing costs, versatility, and pro-
gramming ease, the decision was made to accomplish the data processing on a
PDP-15 computer with 16K words of core memory and two disk storage units
rather than on a larger computer also available at the WES. However, this
decision necessitated rewriting the NASA CCT's to permit processing the data
without exceeding the memory capacity of the computer.

As shown in fig. 5, the original NASA CCT's contain the data for all MSS bands
recorded in sequence for successive pixels. The CCT's are rewritten on four
tapes with each tape containing all data for one spectral band and with the
pixels in the proper sequence. Each pixel value is scaled to a number between
0 and 63 and recorded as a 12-bit word (fig. 6) with the least significant
6 bits containing the pixel radiance value and the most significant 6 bits
left open for use in identifying the pixel.

The values between 0 and 63 can be converted to radiance (in mw/cm^2-SR) by
the equation shown in fig. 7. This equation corrects for the gain of detec-
tors in each of the four MSS bands and for atmospheric effects on the propa-
gation of electromagnetic waves in each of the wavelength bands. Solving
this equation gives the spectral radiance at ground level that would result
in the radiance detected at satellite altitude. This is desireable so that
ERTS-measured radiance values can be correlated with radiance measurements
taken for ground truth purposes.

Data Interpretation

Three methods of interpretation are discussed in the following paragraphs.
The first was developed as an aid in developing the computer programs for
generating sediment concentration maps. The second was a by-product of the
first. The concluding technique is the one used for sediment pattern studies.
It is the most elaborate and promises to have numerous applications in addi-
tion to the one for which it was originally developed.

Land/water Separation

Near infrared radiation is strongly absorbed by water so that band 4 (0.8-1.1 μm)
radiance values measured over water can be expected to be low. Upon examination
of the values, it was found that radiance values over water were normally less
than 0.2 mw/cm^2-SR and were significantly lower than values over land. Thus,
band 4 provides a convenient way to digitally identify values corresponding
to land areas. Band 4 data are scanned on a pixel-by-pixel basis (fig. 8) and
in every case in which the radiance value is less than 0.2 mw/cm^2-SR, a binary
"1" is placed in the first (most significant) bit position of the 12-bit word
containing the pixel value. Every "water" pixel in the data array is identi-
fied in this manner.

The practical value of this is that the data in this form can be easily con-
verted to water distribution maps and map overlays that show locations of
water bodies. A film writing instrument, such as the one shown in fig. 9,
is required. This instrument can be programmed to convert any value recorded
on magnetic tape to a specified shade of gray or black on a piece of photo-
graphic film. Thus, by programming the film writer to give a maximum exposure
whenever a binary "1" occurs in the most significant position of the pixel
word, a map overlay (fig. 10) will be produced wherein water bodies are black
and all other features are transparent.

Conversely, if the film writer is programmed to give maximum exposure only
when there are no binary "1's" in the prescribed position of a pixel word,
the result will be an overlay wherin water bodies are transparent and land
areas are black (fig. 11). This type of overlay is particularly useful for
studying land areas inundated by flood waters and making comparisons with
the surface area during low water levels.

Water Body Inventory

The ability to apply ADP techniques and to distinguish in ERTS-1 data land
pixels from water pixels has produced an unusual "spin-off" capability that
has been used extensively at the WES to produce from the ERTS-1 data reservoir
inventories needed in connection with the National Dam Safety Program. This
capability has been exploited to produce inventories of water bodies for much
of the southeastern United States.

The reservoir inventory (fig. 12) is a list that identifies every discrete
water body by latitude and longitude, and gives an estimate of its water

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surface area. To produce these inventory lists a computer program is used that we call the contiguity routine. In the continguity routine, the first scan line is placed in computer memory, where it may be thought of as a line of zeros and ones, (corresponding to land and water) as in fig. 13. Each individual "water" pixel is placed in a separate file on a disc, so that in the example, pixel 1-3 (line 1, pixel number 3) is in one file, pixel 1-7 is in another file, and so on. Scan line 2 is then placed in memory, and a search routine is then initiated. All pixels occupied by zeros are passed over, since they represent land. However, the discovery of a 1 in pixel 2-6 initiates a search routine:

Step	Question	Response	Action
1	Is pixel 1-5 a 1	No	Go to step 2
2	Is pixel 1-6 a 1	No	Go to step 3
3	Is pixel 1-7 a 1	Yes	Place pixel 2-6 in the same file as pixel 1-7; go to pixel 2-7 and resume search

The effect of this routine is to assemble a separate file for each group of contiguous pixels.

Upon completion of the search of scan line 2, scan line 1 is dropped from memory and scan line 3 is placed in memory (fig. 14). The search routine will detect the fact that the files holding pixels 2-6 and 2-10 are connected by a line of contiguous pixels in line 3. When this occurs, the two files are consolidated in a new file on the disc. After all scan lines have been searched, the disc contains a separate file for each water body, and the number of entries is equivalent to the number of pixels, which in turn can be used to calculate an approximate surface area. This process requires 1-2 hrs of computer time per ERTS scene depending upon the number of water bodies in the scene.

The latitude and longitude which appears on the inventory list is the position of the pixel at the midpoint of the longest line of pixels in the file, representing the water body (fig. 15).

Sediment Particle and Solute Concentration Maps

Use of the ERTS-1 data for the purpose of mapping sediment particle and solute concentration is, in actuality, a two step operation. In the first step, water pixels are separated from land pixels using band 4 data, and water pixels are identified by a binary "1" in the most significant position as previously mentioned. The computer tape with pixels identified in th's manner is then used as a mask for separating water and land pixel values on the tapes containing band 1, 2, and 3 data. Data in these bands do not otherwise permit a clear land/water separation.

In the second step, a computer program combines the data from bands 1, 2, and 3 to define the spectral reflectance for each pixel. The spectral reflectance for each pixel is then compared with one or more reference spectra. If a match occurs, the pixel is identified according to the reference spectrum it matches. At the same time, the geometric relationship of each pixel comprising a scene is retained so that the results of analysis can be used to generate maps.

To accomplish the second step two inputs to the computer are required—the reference spectrum (or spectra) and a digital magnetic tape for each MSS band in a format compatible with the PDP-15 computer.

Determination of reference spectra. Reference spectra may be derived from one of three possible sources—prediction models, ground truth measurements, or ground truth coupled with MSS measurements. The exact procedure used to obtain reference spectra depends to a very large extent on the intended use of the ERTS data.

Prediction models suitable for defining the spectral characteristics of different objects or materials are being developed, but at this point are not developed to the extent that they can be used very extensively for remote sensor data interpretation. One such model developed at the WES has been used to determine the optimum film/filter combination for detecting a target whose spectral reflectance characteristics are known. In addition, the model computes the proper F-stop and shutter speed required to make the target appear on the film with a specified contrast ratio against its background or surroundings. This same model can be used to compute the spectral signature of any target as it would appear to a sensor at specified altitude and atmospheric conditions providing the scattering and absorption properties of the target are known.

Another model is being developed at Colorado State University by Dr. James A. Smith, et al. Their model computes the apparent directional reflectance of vegetation, on the basis of solar angle and view angle, canopy geometry and optical properties, and soil background.

Reference spectra can also be derived directly from ground truth measurements of the spectral reflectance of objects or features of interest. Measurements can be made using any one of several relatively inexpensive instruments (fig. 16) designed for this purpose. For best results the instrument should view a target through the same spectral bands as the ERTS-1 MSS and measurements should be corrected for atmospheric effects. Measurements should be made within a time frame that includes the satellite overpass.

The process of deriving reference spectra from ground truth coupled with MSS measurements is the least satisfying approach from a scientific standpoint, but it nevertheless results in a useful coupling of satellite and ground observations. Ground data are required on the physical properties of the material (and its environment) and their anticipated effect on the

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reflectance spectrum that will be measured by the MSS. In the case of sus-
pended sediments, measurements of suspended material concentration, water
temperature, conductivity, turbidity, dissolved oxygen, current velocity/
direction, spectral transmittance, secchi depth, and pH might be considered
appropriate. Measurements should be taken at a sufficient number of loca-
tions to adequately characterize the test area. Fig. 17 shows a typical
sampling pattern that was used in our study of selected Chesapeake Bay
estuaries.

Spectral data to be used in deriving reference spectra are obtained from
computer printouts of the radiance values for bands 1, 2, and 3 (fig. 18).
Values corresponding to each of the ground data collection locations are
located in the printout and extracted to define a reference spectrum. In
fig. 18 the reference spectrum is shown for the point inclosed in the small
box. (Note that pixel values from land have not been printed as a result
of applying the band 4 mask.) The sediment concentration determined from
ground truth taken at that point was 6.5 mg/l.

When the measurements of concentrations of suspended sediments were plotted
against the reference spectra determined in the manner described, the result
is as shown in fig. 19. The center of the three lines on the graphs is the
calculated regression line. The dashed lines define the limits of potential
error introduced by instrumental variations (approximately ± 2.0 percent of
full scale) in the ERTS MSS. With this in mind, a good correlation would
be one in which all points fall inside the error band.

Given the correlations between sediment concentration and spectral composi-
tion as indicated by the Rappahannock data (fig. 20), it is possible to
establish reference spectra. Instrumental variations preclude selection
of a list of three radiance values, one for each band for each suspended
sediment concentration; instead they must be ranges of values for each sus-
pended sediment concentration range. Determination of ranges is largely
a subjective process which is governed by the following guidelines: (a)
the upper and lower limit of each range must relate to a whole number
(between 0 and 63) that will occur on the CCT's, (b) the number of differ-
ent ranges is reasonable for the sediment concentration range of the test
area, and (c) most of the data within the limits of potential error fall
into one of the classes. When these guidelines are applied to the
Rappahannock data, the classes are as shown in fig. 20.

The Rappahannock River drains an area that is characterized by soils that
are predominantly brown to dark brown in color. The York River, on the other
hand, drains an area that is characterized by reddish sandy soil of the Cahaba
series. Therefore, band 2 (visible red) radiance values for the York might be
expected to be higher than those for the Rappahannock. The spectral signa-
tures of the suspended materials in these two rivers are not as distinct as
one would hope. If the correlation bands for these two rivers are placed
on top of each other, as in fig. 21, the bands at the lower end of the sus-
pended material concentration scale (i.e. below about 15 mg/l) overlap so

completely that discrimination between sediment types is clearly impractical. However, at concentrations between 15 mg/l and 25 mg/l, band 3 provides some measure of discrimination, and at concentrations about 25 mg/l, both bands 2 and 3 separate, and thus provide discrimination. Thus, while the discrimination powers of the spectral signatures are far from absolute or ideal, they still appear to permit identification over a part of the range of interest.

Pixel spectrum identification. Having established a reference spectrum for each range of sediment concentration, the next step is to identify each pixel according to the reference spectrum it matches. In the computer program compares the radiance value of each band for each pixel and determines into which class the pixel falls. In effect, the result is a matrix, as illustrated in fig. 22. The radiance value for Band 1 in the figure is 1.14, and this fits into class 1; the value in Band 2 is 0.39, which fits into class 1. However, the value for Band 3 is 0.20, which fits into both classes 1 and 2, as shown in the matrix. The pixel is determined classified when there is a fit (i.e. an "X" in the matrix) in all three bands in any one class. When this condition is met, the program assigns a map symbol and a class value to that pixel. Upon the completion of the pixel-by-pixel comparison, there is in effect a new data file containing the location class number and map symbol of each pixel. If a pixel spectrum does not fit any of the reference spectra, that pixel is defined as unclassified, which is in effect a fifth category.

Map generation. This file can then be used to print out a map of the distribution of suspended sediment classes, as illustrated in fig. 23. Note especially the zeros, (which represent "no classification") and note that they occur most commonly near the land-water interface. There may be at least two reasons for this:

    a. Shallow water may be causing the reflectance from the water to be modified by reflectance from the bottom.

    b. Small-scale sediment clouds may be occuring in the near-shore zone as a result of shore-line erosion.

The basic data file can also be used as input to a film-writer, which can construct a photomap showing sediment concentration classes as shades of grey. In this procedure, an optical density is assigned to each sediment concentration class. In this case, the values listed in fig. 24 were used. The result is illustrated in fig. 25. Note that in this illustration only three classes of sediment concentrations were used.

SUMMARY

The WES had developed an analytical procedure which considers the ERTS-1 MSS as a part of a reflectance spectrophotometer. ADP techniques requiring only very limited computer capability are utilized to search the data defining the spectral reflectance characteristics of a scene on a pixel-by-pixel

basis, identify each pixel with the reference spectrum it matches, and
generate maps that show locations where spectrum matches occur and identify
the spectrum that was matched. If the reference spectra are known to relate
to a specific condition or feature on the ground, a map of the distribution
of that condition or feature can be output as a dimensionally accurate over-
lay to maps of any selected scale. An example was given in which a map was
produced showing the distribution of specific suspended sediment concentrations
in an estuary of the Chesapeake Bay. By-products were described in which the
ERTS-1 data were used to generate map overlays identifying water bodies and
inventories of water bodies giving location and estimated size.

Fig. 1. Reflectance Spectrophotometer

GROUND DATA
RECEIVING STATION

RECEIVER

COMPUTER
TAPF 3

PHOTOGRAPHS

TRANSMITTER

CH 4

CH 3

CH 2

CH 1

WAVELENGTH, μ

1.1

1.0

0.9

0.8

0.7

0.6

0.5

GROUND
SURFACE

100 NM

OPERATION OF MULTISPECTRAL
SCANNER ABOARD THE
ERTS-1 SATELLITE
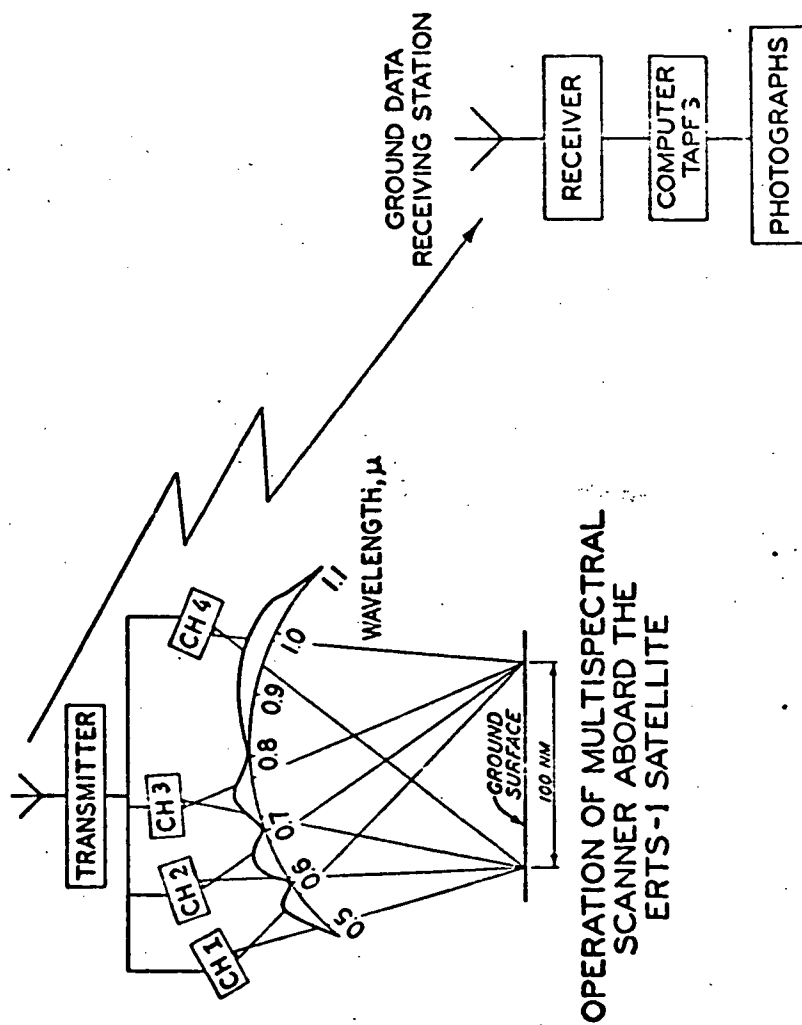
Fig. 2. Earth Resources Technology Satellite (ERTS-1)
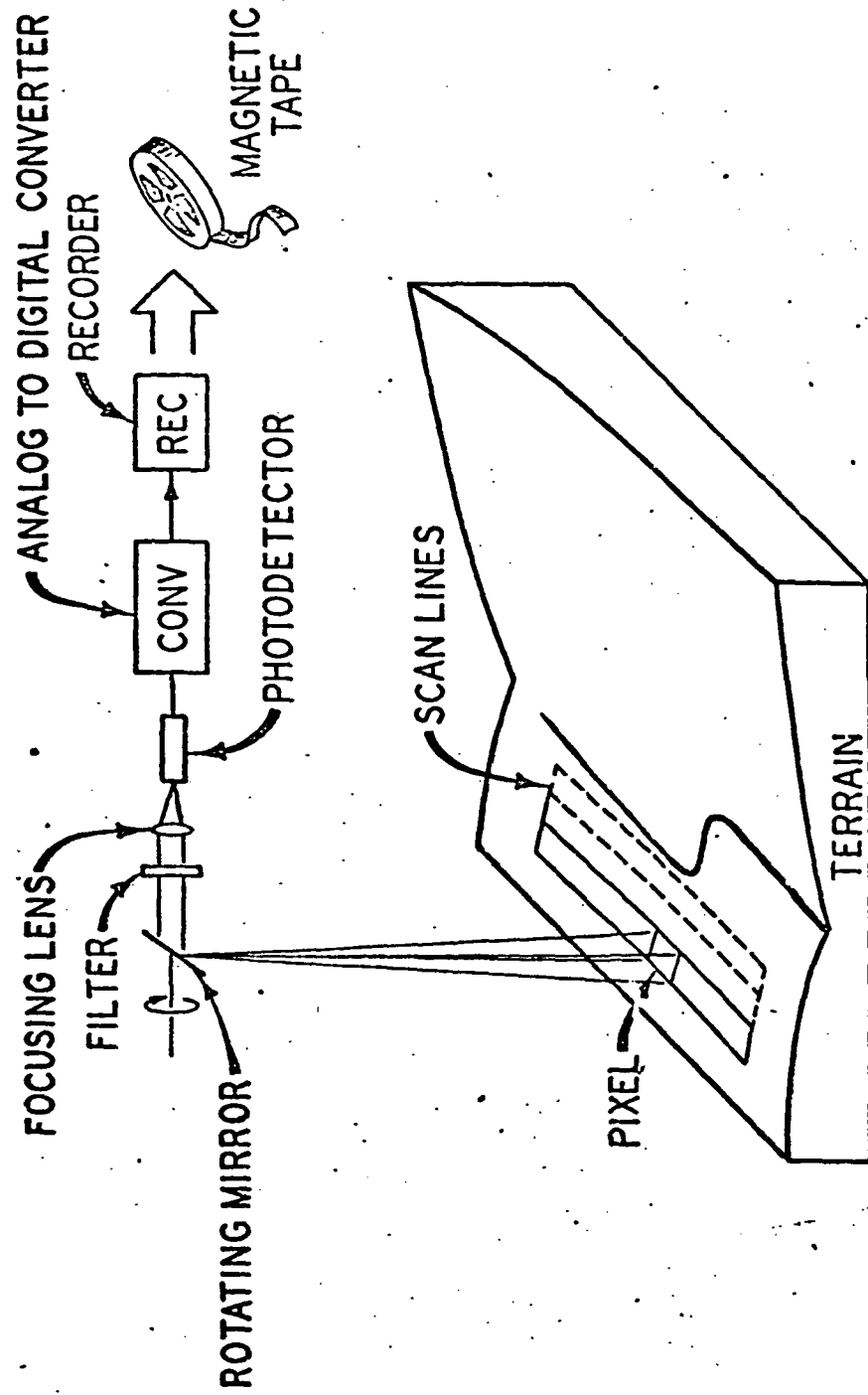
Fig. 3. Concept of ERTS MSS Scanning Function
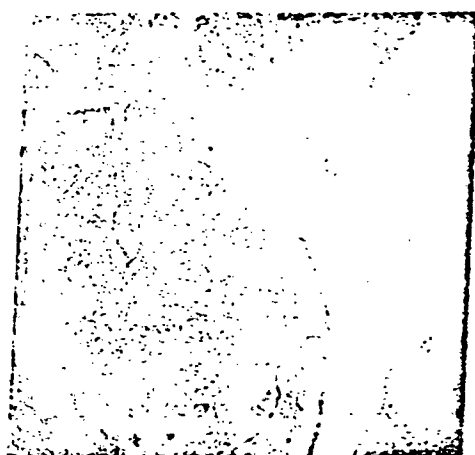
MSS BAND 1
(0.5-0.6 MICROMETERS)

MSS BAND 2
(0.6-0.7 MICROMETERS)

MSS BAND 3
(0.7-0.8 MICROMETERS)
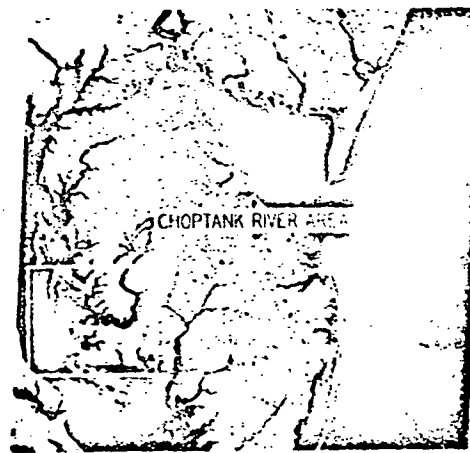
MSS BAND 4
(0.8-1.1 MICROMETERS)

Fig. 4. A Portion of Chesapeake Bay Study Area Viewed from Earth Resources
Technology Satellite (ERTS-1)

DATE: 10 OCTOBER 1972

BASIC NASA FORMAT

PIXEL 1	PIXEL 2	PIXEL 3

BAND 1
BAND 2
BAND 3
BAND 4

16	24	19	43	18	19	45	55	16	20	50	61

RADIANCE VALUE OF
PIXEL 3, BAND 4

WES RE-FORMAT

| 16 | 18 | 16 | Etc. | TAPE 1 = BAND 1

| 24 | 19 | 20 | Etc. | TAPE 2 = BAND 2

| 19 | 45 | 50 | Etc. | TAPE 3 = BAND 3

| 43 | 55 | 61 | Etc. | TAPE 4 = BAND 4

PIXEL 1
PIXEL 2
PIXEL 3
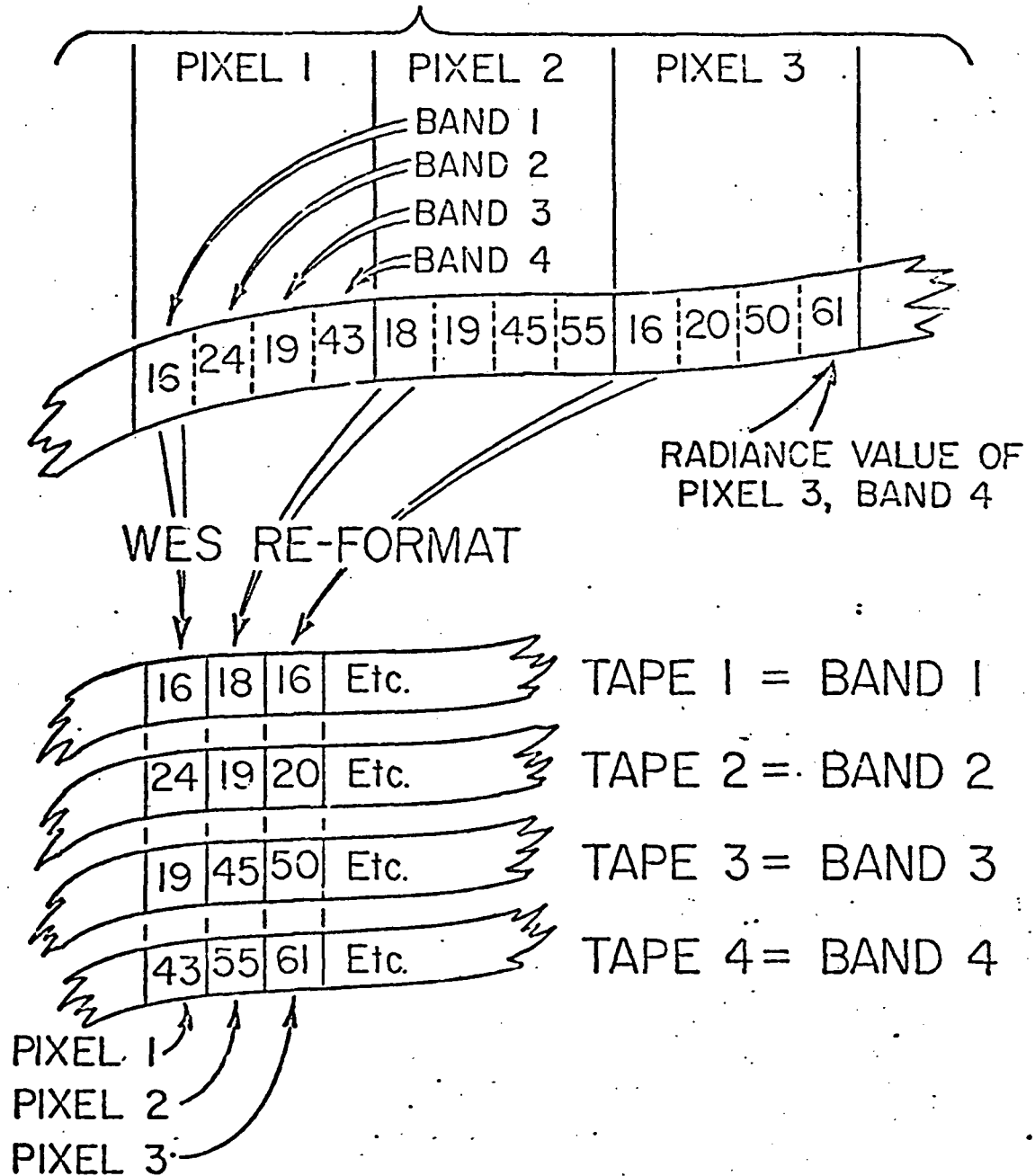
Fig. 5. Conversion of NASA Format to WES Format

ONE PIXEL VALUE
(12 BITS)

6 BITS LEFT "EMPTY" FOR FURTHER USE

6 BITS USED TO RECORD RADIANCE VALUE
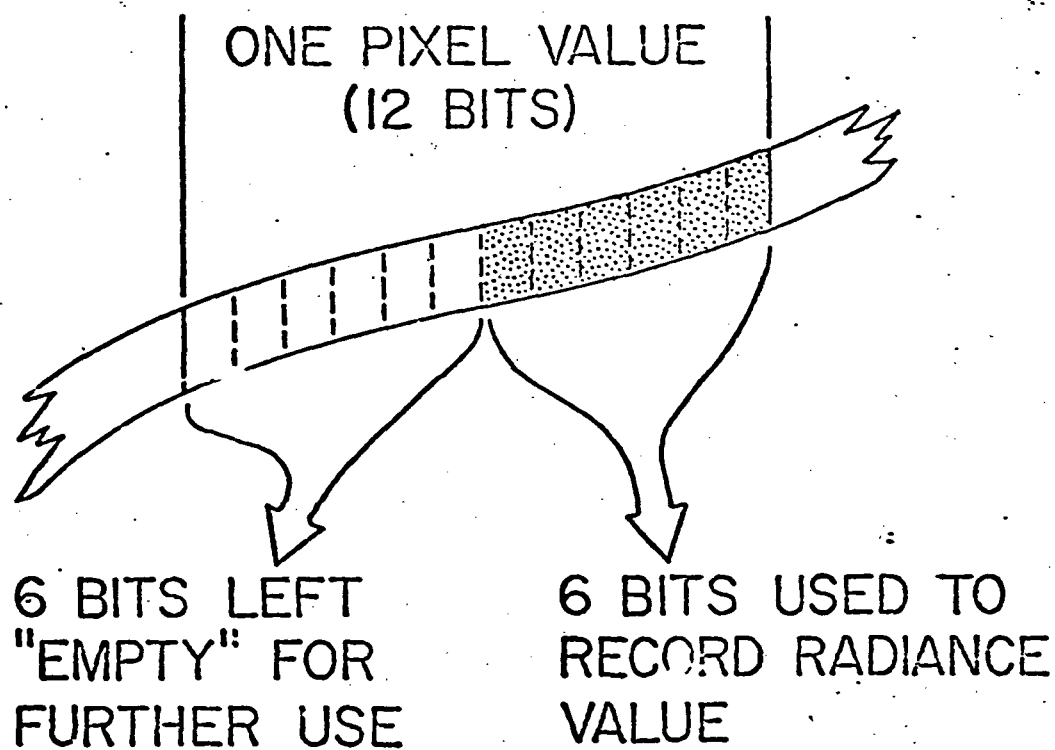
Fig. 6. Initial Utilization of 12-Bit Word

$$H = \frac{x \cdot M_i}{63 \cdot T_i}$$

WHERE: H = radiance in mw/cm^2-SR

x = value from computer compatible tape (CCT)

M_i = gain setting (from NASA)

T_i = atmospheric transmittance (from AFCRL model)

$M_1 = 2.48$	$T_1 = 0.69$
$M_2 = 2.00$	$T_2 = 0.75$
$M_3 = 1.76$	$T_3 = 0.68$
$M_4 = 4.60$	$T_4 = 0.76$

Fig. 7. Conversion of CCT Values to Radiance Values

WATER PIXEL

LAND PIXEL

DIGITAL RECORD:
ALL VALUES
LESS THAN 0.2
FLAGGED

| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

DIGITAL RECORD
OF RADIANCE
VALUES

| 0.9 | 0.7 | 0.5 | 0.1 | 0.7 | 1.0 | 0.8 | 0.9 |

RADIANCE

1.2
1.0
0.8
0.6
0.4
0.2
0

THRESHOLD = 0.2

WATER   LAND

ONE PIXEL

ERTS-1
BAND 4
SCAN LINE

Fig. 8. Water Pixels vs. Land Pixels

OPTRONICS INTERNATIONAL, INC.
CHELMSFORD, MASS.
PHOTOMATION MARK II SYSTEM P-1700
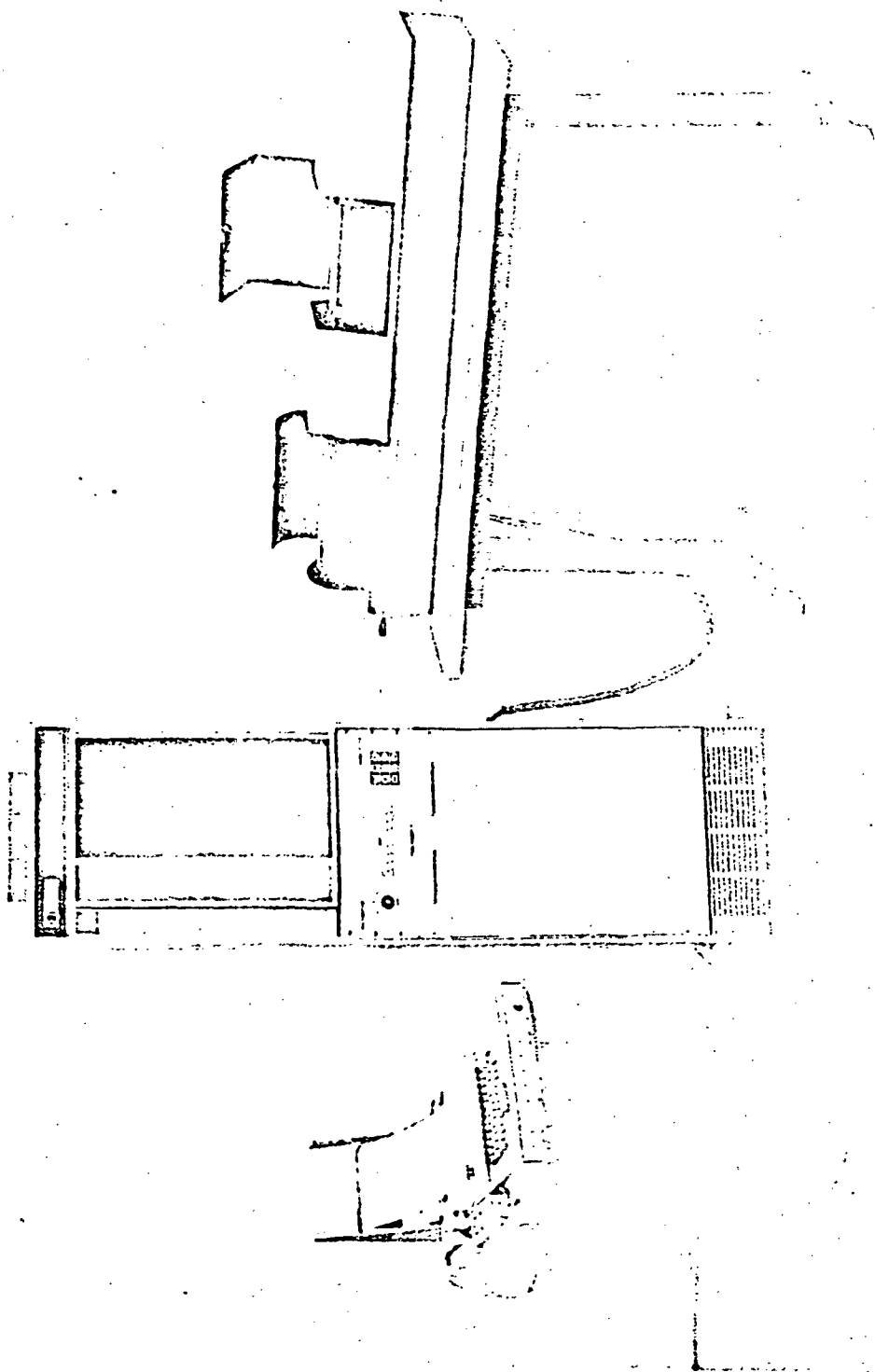
Fig. 9. Film Reader/Writer
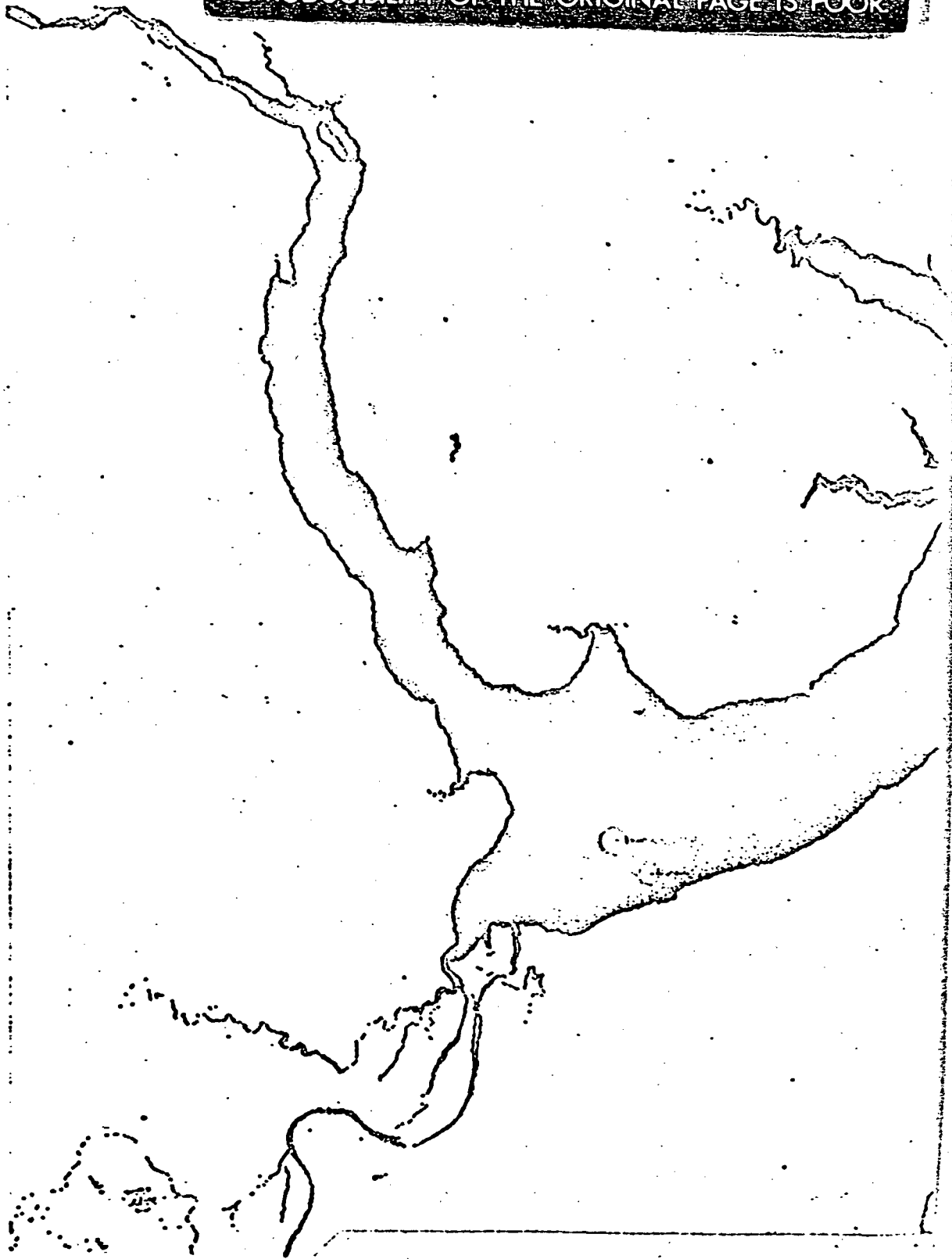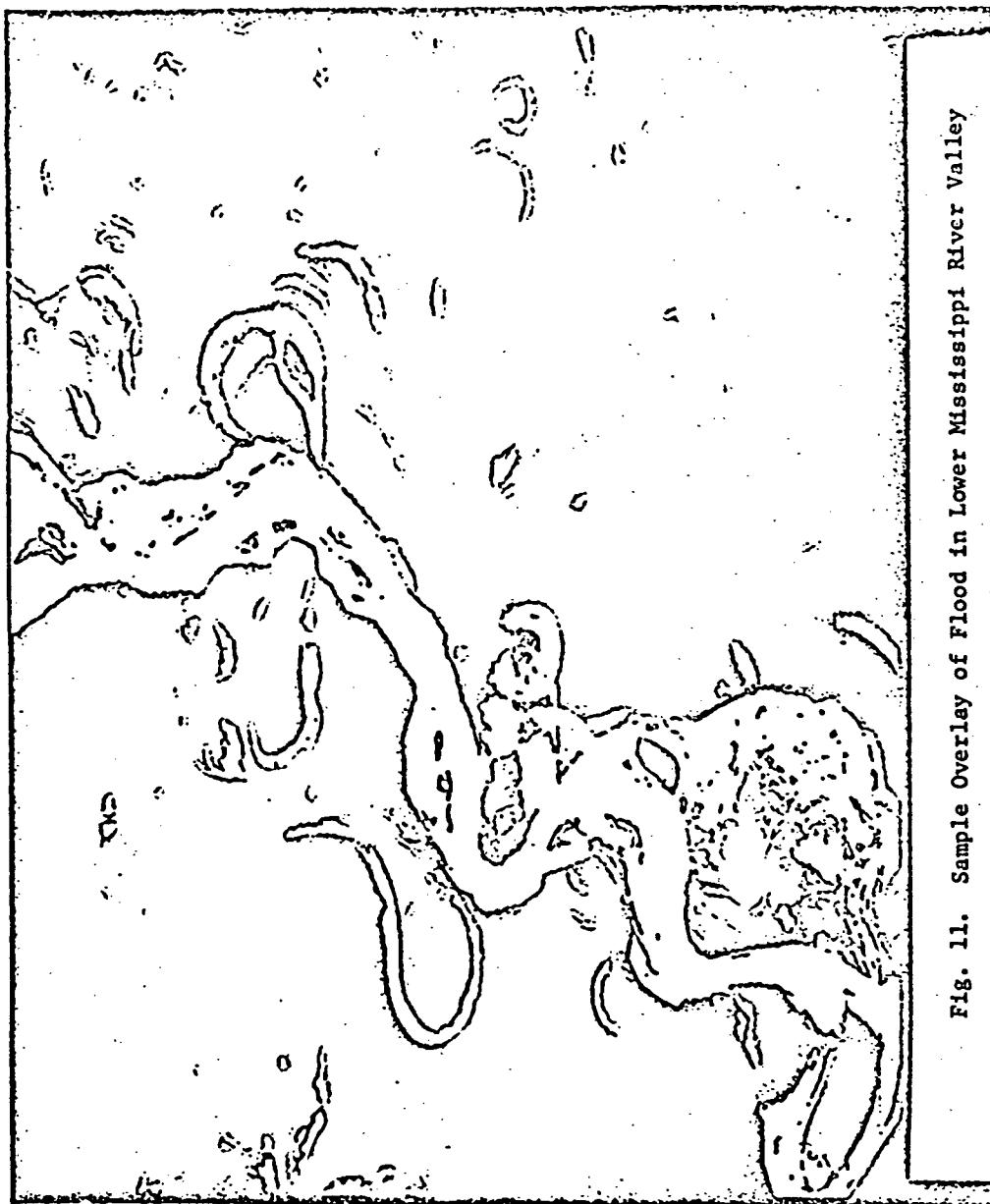
Fig. 11. Sample Overlay of Flood in Lower Mississippi River Valley

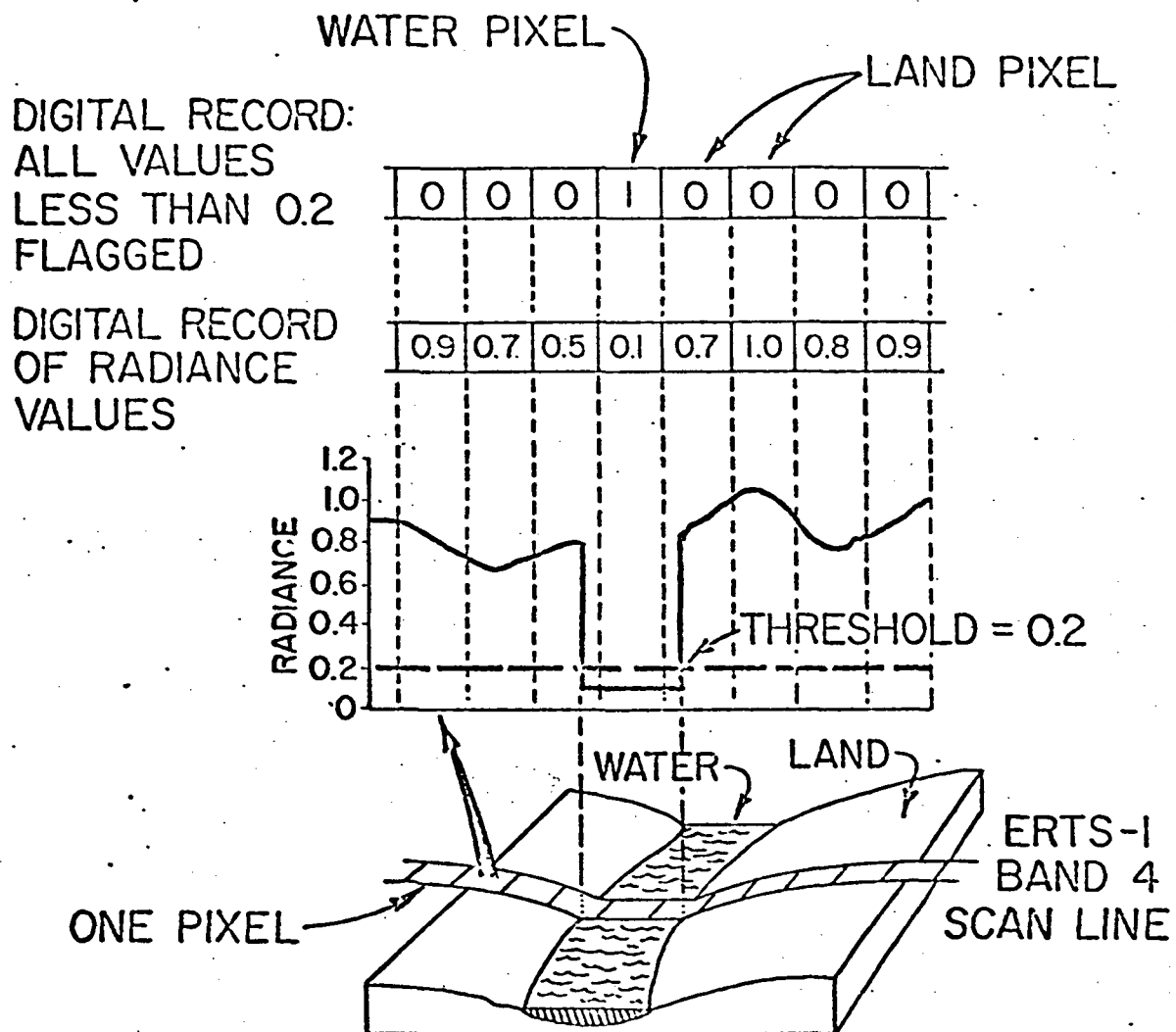| LATITUDE DEG MIN	LONGITUDE DEG MIN	PIXEL COUNT	EST. SURFACE ACRES
N35- 9.6	W 82-21.4	45.	50.
N35- 7.0	W 82- 4.8	1.	1.
N35- 9.2	W 82-18.9	2.	2.
N35- 9.6	W 82-21.7	1.	1.
N35- 9.6	W 82-21.9	3.	3.
N35- 6.3	W 82- 1.1	1.	1.
N35- 6.2	W 82- 1.0	1.	1.
N35- 9.5	W 82-21.9	1.	1.
N35- 8.8	W 82-17.6	2.	2.
N35- 6.2	W 82- 0.8	19.	21.
N35- 9.4	W 82-21.9	6.	7.
N35- 6.2	W 82- 1.6	2.	2.
N35- 6.1	W 82- 1.3	27.	30.
N35- 9.4	W 82-22.1	1.	1.
N35- 6.0	W 82- 0.7	10.	11.
N35- 6.7	W 82- 5.7	1.	1.

Fig. 12. Sample Printout of Inventory of Surface Water Bodies

PIXEL I → "WATER" PIXELS

SCAN LINE I | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |

SCAN LINE 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |

SETS OF CONTIGUOUS PIXELS
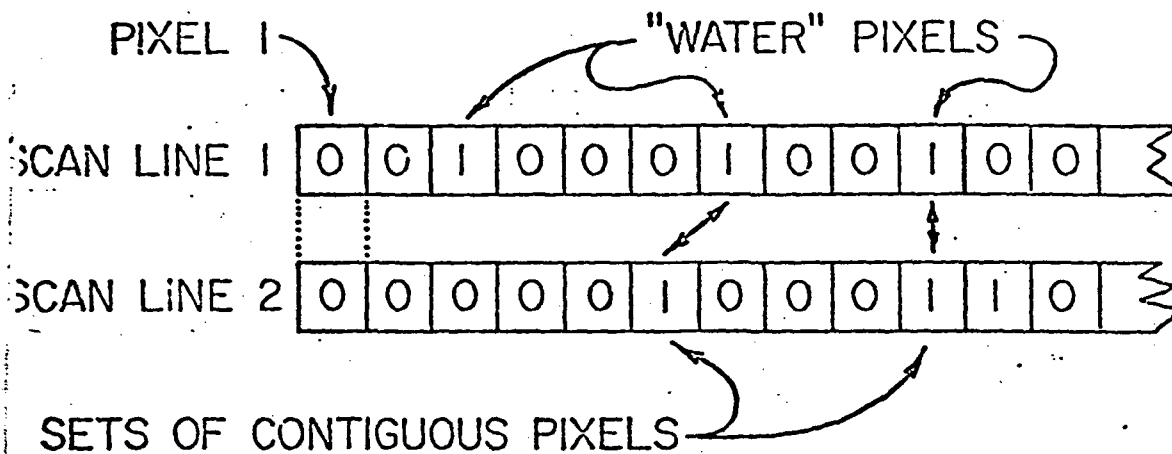
FILES ESTABLISHED FOR SCAN LINE I	FILE A	FILE B	FILE C
	1 – 3	1 – 7	1 – 10
FILES AFTER SEARCH OF SCAN LINE 2	FILE A	FILE B	FILE C
	1 – 3	1 – 7	1 – 10
		2 – 6	2 – 10
			2 – 11

Fig. 13.   The Contiguity Rule

PIXEL I

SCAN LINE 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | >

SCAN LINE 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | >
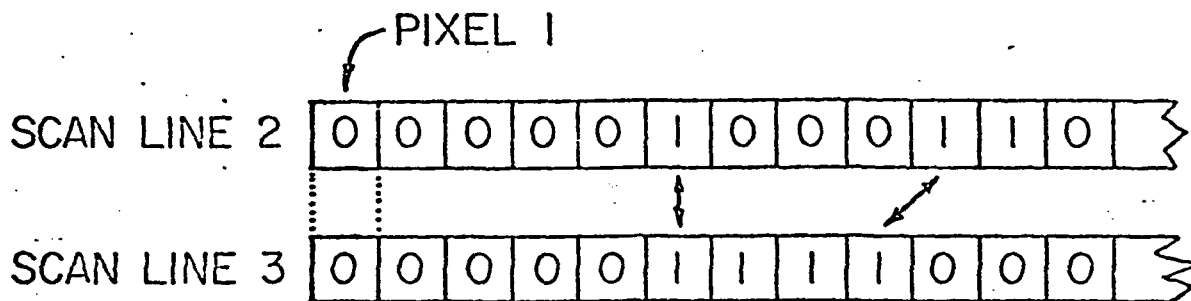
STATUS OF FILES AFTER SEARCH OF SCAN LINE 2	FILE A	FILE B	FILE C	
	1 - 3	1 - 7	1 - 10	
		2 - 6	2 - 10	
			2 - 11	

STATUS OF FILES AFTER SEARCH OF SCAN LINE 3	FILE A	FILE B	FILE C	FILE D
	1 - 3			1 - 7
				1 - 10
				2 - 6
				2 - 10
				2 - 11
				3 - 6
				3 - 7
				3 - 8
				3 - 9

Fig. 14. File Consolidation

ONE PIXEL

WATER BODY

SELECTED AS
"CENTROID" PIXEL

LATITUDE AND LONGITUDE OF WATER BODY
SPECIFIED BY LOCATION OF "CENTROID" PIXEL

Fig. 15. Selection of "Centroid" Pixel

Fig. 16. Radiometer for ERTS-1 Studies

Fig. 17. Location of Ground Control Points in York River

114.114.114.114.114.114.114.114.114.114.114.119.125.119.114.114
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114.114.114.114.114.114.114.114.114.108.114.136.114.114.114.114
108.108.114.114.114.114.114.114.114.114.125.114.108.114.114.108
114.114.114.114.114.114.114.114.114.131.119.114.114.119.119.114
102.102.108.119.108.108.119.108.125.119.108.108.108.108.102.108
114.114.119.114.119.114.114.119.   119.114.114.114.114.114.119
114.114.114.─── 114.114.108.   136.108.114.114.114.114.114.114
114.114.114.114 11─.114.114.136.114.114.114.114.114.108.114.114
114.114.114.──.108.11─.─5.114.125.114.114.108.114.108.108.114
114.114.102.1─4.1─4.   119.─08.114.114.114.114.114.114.114.114
108.108.108.108.11─.119.102.108.─08.108.108.119.108.108.108.108
119.114.114.11─.125.1─4.114.114.119.─14.114.114.114.119.119.114
114.114.114.   114.114.114.114.114.114.114.1─4.114.114.114.114
114.114.119.119.─14.114.1─6.114.114.119.114.11─.114.114.114.114
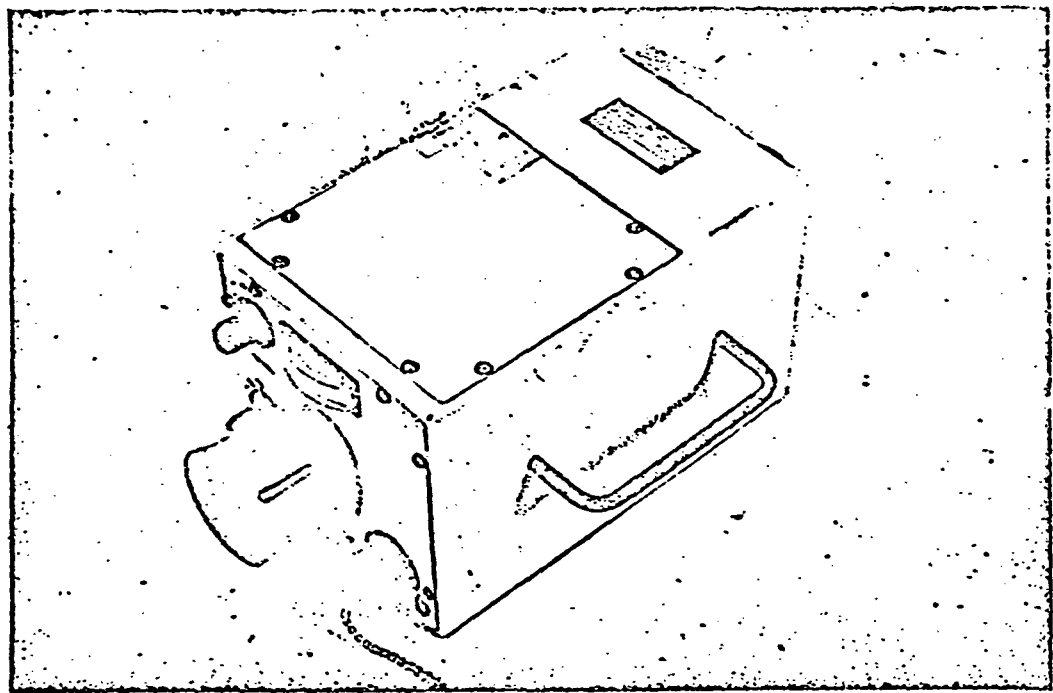114.125.125.114.1─4.114.114.114.114.114.114.114.11─.114.114.114
119.131.119.119.11─.119.114.1─2.114.11─.119.114.114.─14.119
125.108.108.119.108.119.108.11─

SPECTRUM WHEN SUSPENDED MATERIAL IS 6.5 mg/l

125.119.119.119.119.12─
119.119.114.119.119.1─4.119.119
119.119.119.119.114.11─.114.119
131.131.131.125.125.125.125.12─
142.142.142.142.142.131.─31.142
136.136.136.142.142.136.136.13─
148.148.159.148.148.148.14─.148
154.154.142.142.154.154.14─.15─
148.148.148.148.148
148.148.148.148
154.142.154.14─
159.142.142.14─

159.148.159.159.148.142.142.142.142.142.142
154.154.154.154. SPECTRUM WHEN   136.136.136
159.148.148.159.148. SUSPENDED MATERIAL 136.136.136
154.154.154.154.148. IS 6.5 mg/l   131.125.131
154.154.154.154.142.142.142.142.131.131.142.131
136.136.142.154.142.142.154.142.154.136.142.136.136.125.125.125
148.159.159.159.159.165.159.159.148.148.148.148.142.142
154.154.154.159.154.154.154.154.154.154.148.136.136.136
142.148.159.159.148.142.148.148.159.148.142.136.136.136
148.148.131.148.131.   148.154.154.154.148.148.148.148.131
142.142.154.142.   142.142.142.154.154.154.142.142.142
154.142.142.142.142.136.136.136.136
148.159.148.159.148.142.142.142
154.154.154.148.148.148.148
148.148.148.148.142.136.142
148.148.154.148.131.131.131
142.142.131.   154.154.154.142.142.131.131
136.136.131.131.136.131.136.131.142.136.142.142.136.131.131.136
142.142.148.142.125.142.142.142.125.142.148.148.148.142.142.125
148.136.136.148.148.154.148.136.136.136.136
142.142.136.142.142.142.136.136.136.136.136
131.148.148.148.148.131.131.131.131.131
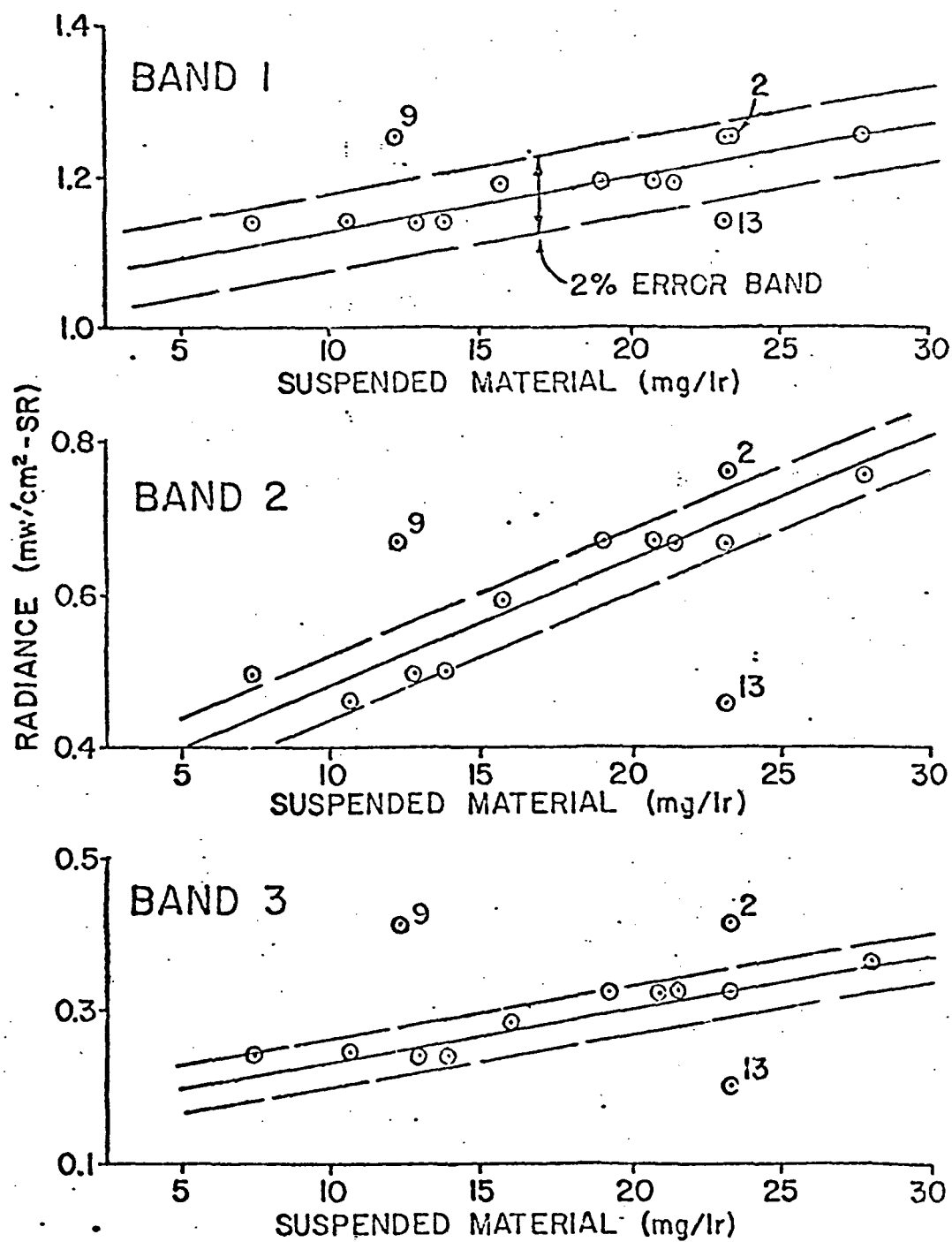142.142.   142.131.131.142.131

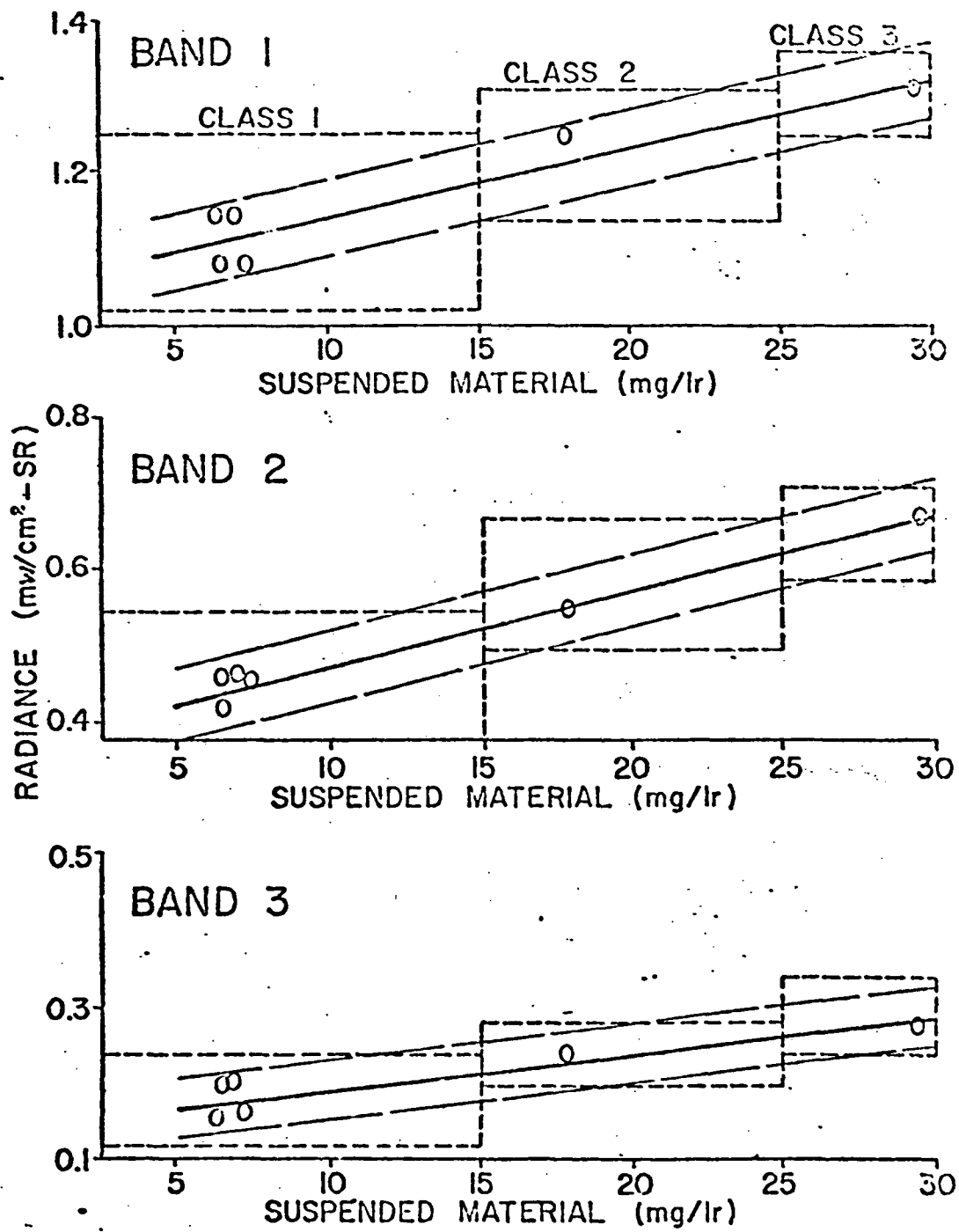Fig. 19. Radiance vs. Suspended Material – York River Estuary

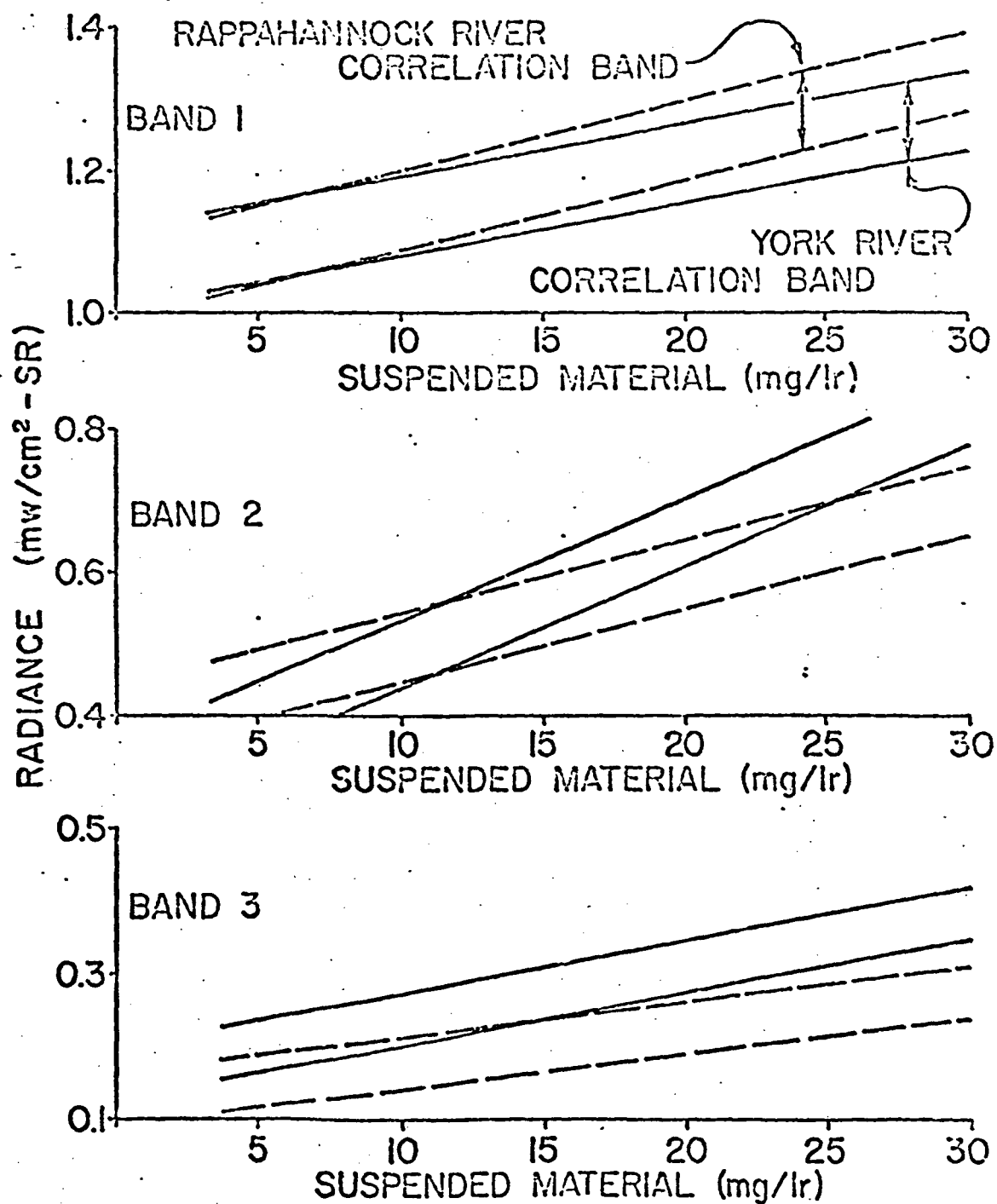Fig. 20. Radiance vs. Suspended Material — Rappahannock River Estuary

Fig. 21. Comparison of Radiance Signatures of York and Rappahannock Rivers

RADIANCE (mw/cm²-SR) ERTS-1 MSS BAND

			CONCENTRATION OF SUSPENDED SEDIMENTS (mg/lr)	MAP SYMBOL	CLASS
1	2	3			
1.02–1.31	0.38–0.55	0.08–0.28	0–10	–	1
1.36–1.48	0.46–0.71	0.16–0.32	10–20	+	2
1.48–1.59	0.76–0.84	0.23–0.32	20–30	✳	3
1.48–1.59	0.76–0.84	0.36–0.41	>30	#	4
1.14	0.39	0.20	0–10	O UNCLASS.	

REFERENCE SPECTRA

PIXEL VALUES

ASSIGNED TO PIXEL BY COMPUTER PROGRAM — – 1

CLASSIFICATION MATRIX

BAND NO.

SEDIMENT CONCENTRATION CLASS	1	2	3
1	X	X	X
2		X	X
3			
4			

Fig. 22. Classification of Pixels

```
BAND 1 = 1.36
+ = BAND 2 = 0.46
BAND 3 = 0.24
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SEDIMENT CONCENTRATION

CLASS	OPTICAL DENSITY
UNCLASSIFIED	3.0
1	1.68
2	1.08
3	0.49
LAND	0.0

Fig. 24. Optical Densities Used as Photomap of York River

SUSPENDED MATERIAL
CONCENTRATION
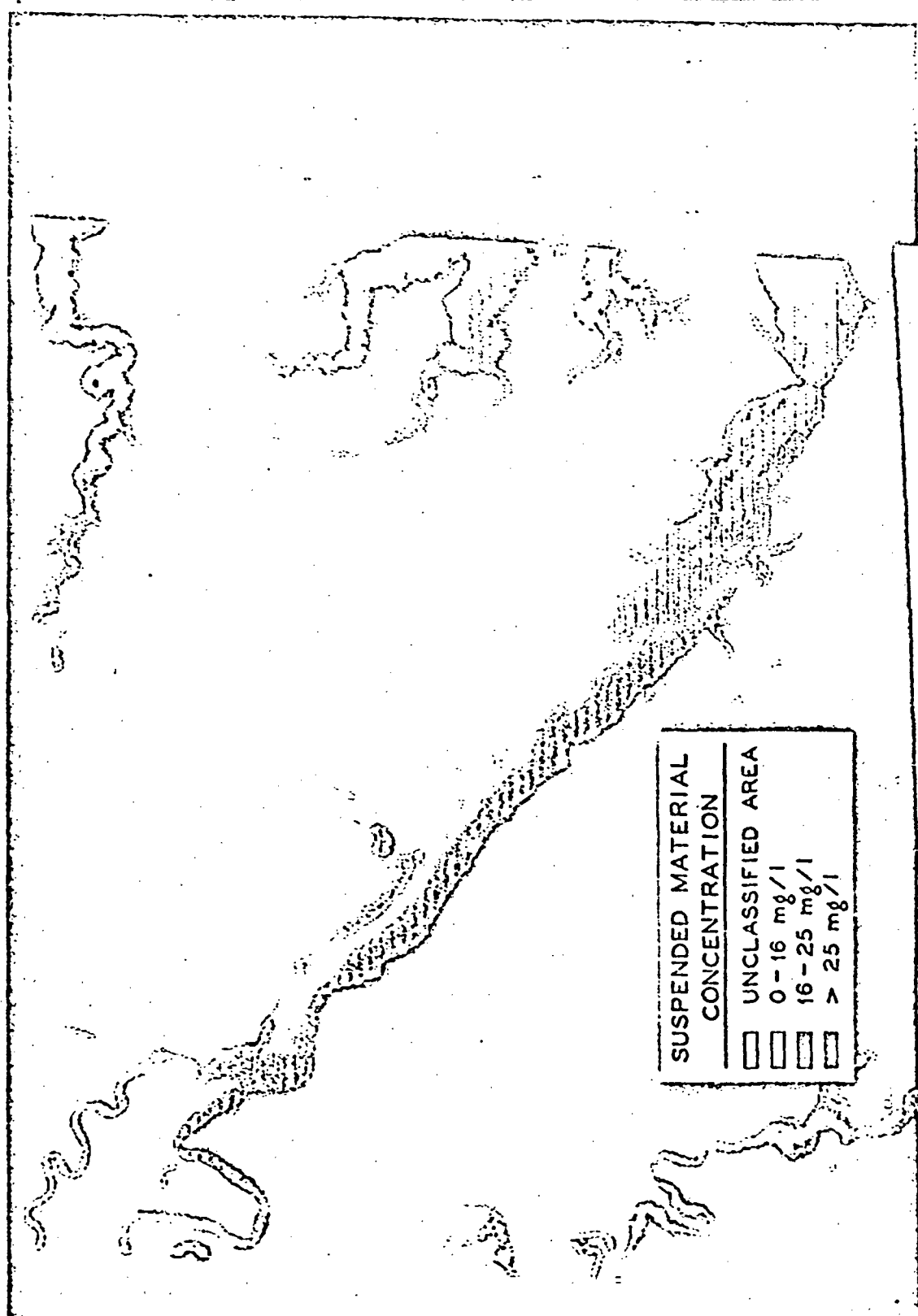
UNCLASSIFIED AREA
0 – 16 mg/l
16 – 25 mg/l
> 25 mg/l

Fig. 25. Photomap Derived From Computer Analysis of ERTS-1 Data